

University of Dundee

The 2015 Garrod Lecture

Davey, Peter

Published in:
Journal of Antimicrobial Chemotherapy

DOI:
[10.1093/jac/dkv214](https://doi.org/10.1093/jac/dkv214)

Publication date:
2015

Document Version
Peer reviewed version

[Link to publication in Discovery Research Portal](#)

Citation for published version (APA):
Davey, P. (2015). The 2015 Garrod Lecture: why is improvement difficult? *Journal of Antimicrobial Chemotherapy*, 70(11), 2931-2944. <https://doi.org/10.1093/jac/dkv214>

General rights

Copyright and moral rights for the publications made accessible in Discovery Research Portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from Discovery Research Portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain.
- You may freely distribute the URL identifying the publication in the public portal.

Take down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Why Is Improvement Difficult?

Garrod Lecture 2015

Peter Davey

Professor and Lead for Clinical Quality Improvement, Medical Education Institute, University of

Dundee, Mackenzie Building, Kirsty Semple Way, Dundee DD24BF

Telephone 01382 383800

Email p.g.davey@dundee.ac.uk

Total word count 6216

Funding: none

Abstract (250 words)

The pressing need to measure and improve antibiotic use was recognised over 40 years ago, so why have we failed to achieve sustained improvement at scale? In his 2014 Reith Lectures about the future of medicine the US surgeon Atul Gawande said that failure in medicine is largely due to ineptitude (failure to use existing knowledge) rather than ignorance (lack of knowledge). Consequently it is notable that most Interventions to improve antimicrobial prescribing are either designed to educate individual practitioners or patients about policies or to restrict prescribing to make practitioners follow policies. Interventions that enable practitioners to apply existing knowledge through decision support, feedback and action planning are relatively uncommon. There is an urgent need to improve the design and reporting of interventions to change behaviour. However, achieving sustained improvement at scale will also require more profound understanding of the role of context. What makes contexts receptive to change and what elements of context, under what circumstances, are important for human performance? Answering these questions will require inter-disciplinary work with social scientists to integrate complementary approaches from Human Factors and Ergonomics, Improvement Science and Educational Research. We need to rethink professional education to embrace complexity and enable teams to learn in practice.

26 Workplace based learning of improvement science will enable students and Early Career
27 Professionals to become change agents and transform training from a burden on clinical teams into
28 a driver for improvement. This will make better use of existing resources, which is the key to
29 sustainability at scale.

30 Acknowledgements

31 "I would like to acknowledge three lectures by social scientists that have had a major
32 influence on this paper: "Why is Improvement so hard? Toward a socio-cultural view,
33 "Professor Justin Waring; "Towards a Science of Improvement", Professor Mary
34 Dixon-Woods; "(professional) Learning in Practice", Professor Tara Fenwick.

Introduction

The UK 5 Year Antimicrobial Resistance Strategy 2013-2018 recognises the importance of reducing inappropriate antibiotic prescribing,¹ the implication being that antibiotic resistance is largely a consequence of the selective pressures of antibiotic usage and that reducing these pressures by the judicious administration of antibiotics will facilitate a return of susceptible bacteria or, at least, will prevent or slow the pace of the emergence of resistant strains. At the same time, sepsis kills more people annually in the UK than myocardial infarction or breast, colon and lung cancer combined and delay in effective antibiotic treatment is associated with increased mortality.²⁻⁴ The term antibiotic stewardship is used to capture the twin aims of ensuring effective treatment of patients with infection and minimising collateral damage from antimicrobial use.⁵

The pressing need for antimicrobial stewardship was actually well recognised over 40 years ago⁶ and clear plans for measurement and improvement of antibiotic use followed soon after on both sides of the Atlantic.^{7,8} By the 1990s failure of these initiatives led to worldwide demands for concerted action to limit the development of antibiotic resistance through improvement in the use of antimicrobials.⁹⁻¹³ So why have we failed to achieve sustained improvement at scale? In his 2014 BBC Reith Lectures series *The Future of Medicine* the American surgeon Atul Gawande examined the nature of progress and failure in medicine.¹⁴ He argued that failure in medicine is largely due to ineptitude (failure to use existing knowledge) rather than ignorance (lack of knowledge) and that progress will only be achieved through systems that are better designed to transform care from the richest parts of the world to the poorest. In *The Century of the System* Gawande said that in the 20th Century “we were fooled by penicillin” into thinking that medical progress would come simply from the discovery of new molecules. The misguided quest for simple solutions to complex problems is also seen in attempts to improve healthcare, which Gawande described as either primitive (writing guidelines to tell people what to do) or mediaeval (issuing targets with rewards and penalties to make people follow the guidelines).

60 In this paper I reflect on how we can use systems thinking to achieve sustainable improvement in
61 antimicrobial stewardship at scale. I will focus on the evidence base for improving antibiotic
62 prescribing for hospital inpatients^{15, 16} but the same issues apply to prescribing in primary care. We
63 need to look beyond antimicrobial prescribing to evidence from the social sciences about how to
64 change behaviour,¹⁷ improve systems¹⁸ and apply the findings of educational research to learning in
65 practice.¹⁹

66 Evidence About Improvement

67 Design and Reporting of Interventions to Improve Hospital Antibiotic Prescribing

68 The Cochrane systematic review of interventions to improve antibiotic prescribing to hospital
69 inpatients identified 89 studies published up to end of 2006, which showed that a variety of
70 interventions can change hospital antibiotic prescribing.¹⁵ However, there are still important gaps in
71 the evidence about antibiotic stewardship from the previous systematic review in four key areas.¹⁶

- 72 1. Extraction of more detail about behaviour change techniques by application of control
73 theory to the synthesis of evidence.^{20, 21}
- 74 2. Reducing patients' exposure to antibiotics by targeting the decision to treat or the duration
75 of treatment rather than simply targeting the choice of antibiotic, dose or route of
76 administration.
- 77 3. Balancing measures of unintended consequences, which should be an integral component of
78 any quality improvement intervention.^{22, 23}
- 79 4. The evidence about the impact of interventions on microbial outcomes is relatively weak
80 because only 12 (13%) of studies included robust data about both prescribing and microbial
81 outcomes.

82 In the update to the review¹⁶ we are applying the Behaviour Change Technique (BCT) Taxonomy v1,
83 which is an extensive, consensually agreed hierarchically structured taxonomy of techniques [behavior change
84 techniques (BCTs)] used in behavior change interventions.²⁴ In addition we are applying a recently

published checklist for intervention reporting²⁵ and the editorial policy on describing the content of complex behaviour change interventions from the journal Implementation Science.²⁶ Our review will include literature published up to the end of December 2014 but we decided to publish preliminary findings from studies published up to the end of December 2012 in order to improve the awareness and reporting of BCTs in antimicrobial stewardship interventions.¹⁷ There is a strong evidence base from a wide variety of contexts about the effectiveness of the BCTs of goal setting, self-monitoring, feedback and action planning.¹⁷ We identified 116 studies reporting 123 interventions. Reporting of BCTs was poor, with little detail of BCT characteristics. Goals were reported for all interventions but poorly specified (Figure 1a). Most interventions provided participants with some instruction on how to achieve the goal but nearly half (44%) did not specify higher order goals (i.e. did not explicitly link improvement in process with important clinical, financial or microbial outcomes) and only 9% involved the participants in setting targets (Figure 1a). Although 9% of interventions specified a goal threshold and 4% set a time by which the goal should be achieved (Figure 1a), only one of the 123 interventions specified both goal threshold and timescale. Feedback was reported for 18 (14%) of interventions, action planning and self-monitoring were only used in one intervention (Figure 1b). The literature we reviewed included just one example of a hospital stewardship intervention that included all of the evidence-based BCTs.²⁷ The failure to include participants in goal setting, measures for improvement or action planning means that the design of most published interventions has not been informed by identification of reasons for failure to meet standards, which was identified as an important missing link in the audit cycle over 20 years ago (Figure 2):

“Although many audit studies describe deficiencies in health care, few identify the underlying causes. In consequence, the strategies for change which are developed may not address the fundamental problems. An important link in the audit cycle is missing, and failure to include this step is hampering the success of audit.”²⁸

Unfortunately our review shows that the majority of antimicrobial stewardship interventions still do not consider why prescribers do what they do as opposed to what the guidelines say. They are

111 assuming that failure to follow the guidelines is due to ignorance, whereas failures in medicine are
112 rarely due solely to lack of knowledge and almost always involve barriers to doing the right thing.¹⁴
113 Consequently interventions should include components that increase enablement to implement
114 evidence-based practice, defined as “increasing means or reducing barriers to increase capability or
115 opportunity”.²⁹
116 BCTs that enhance enablement include self-measurement, feedback and action planning.²⁹ The
117 design of stewardship interventions should adopt practical guides to sustainable measurement by
118 clinical teams (Figure 3
119) and readily available online resources that support the design of goal setting, measures for
120 improvement and feedback ^{30, 31}.

121 [The Importance of Action Planning and Actionable Feedback](#)

122 The low frequency of action planning in antimicrobial interventions contrasts with other areas which
123 have demonstrated the success of providing goal-setting, feedback and action planning in changing
124 health professional behaviours.¹⁷ Reducing Antibiotic Prescribing in Dentistry (RAPiD) is a recent
125 clinical trial that provides an example of successful use of action planning to enhance audit and
126 feedback about antibiotic use at scale.³² The RAPiD trial recruited 795 Dental Practices and
127 randomised them into three groups: control (n=163), Audit & Feedback Intervention (n=316) and
128 Audit & Feedback plus TRIaDS BC Intervention. The TRIaDS (Translational Research in a Dental
129 Setting) BC (Behaviour Change) text-based intervention was based on the sections on bacterial
130 infections, in the published SDCEP (Scottish Dental Clinical Effectiveness Programme) clinical
131 guidance on ‘Drug Prescribing for Dentistry’³³ These were coded for the presence/absence of BCTs
132 using the BCT taxonomy (Table 1).²⁴ Two BCTs were identified: instruction on how to perform the
133 behaviour (Sub-Goal specification); and provide information about health consequences of
134 performing the behaviour (Higher Order goal specification). These BCTs were therefore selected for
135 inclusion within a text-based intervention (Table 1). The SDCEP guidance included behavioural
136 instruction relating to pre-decision processes, *i.e.*, whether or not it is appropriate to prescribe

137 antibiotics; and post-decision processes, *i.e.*, ways to optimise antibiotic prescribing once the
138 decision to prescribe had been made. The Text Intervention only included the BCTs that focussed on
139 the pre-decision processes. Where possible, the exact wording from the SDCEP guidance document
140 was used but some recommendations were combined to shorten the text (Table 1). A number of
141 potential BCTs coded in the guidance had to be excluded from the final text-based intervention due
142 to insufficient specification of behaviour. For example, the behaviour ‘take care’ within ‘take care
143 when prescribing these antibiotics to vulnerable groups’ was not explicit enough to be included as
144 ‘instruction on how to perform the behaviour’. Note that the instruction *“This should be the first
145 step even if patients request antibiotics and even when time is short”* was added to the guideline
146 recommendation to use local measures first following consultation with Dentists. Antibiotic
147 prescribing in the intervention groups was 6% lower than in the control group. In addition antibiotic
148 prescribing was 6% lower ($p=0.005$) for groups receiving the Behaviour Change (BC) intervention vs
149 groups receiving Audit & Feedback without any written BC intervention.

150 The RAPiD trial shows that evidence-based goal setting can be used to enable effective action
151 planning at scale to reduce unnecessary antibiotic prescribing in primary care. A study of the
152 development of an antimicrobial stewardship intervention in a neonatal ICU (NICU) showed that It
153 may be more challenging to design actionable feedback in some hospital settings (Table 2).³⁴⁻³⁶ The
154 NICU staff were opposed to individualised feedback on the grounds that it was hard to assign
155 individual responsibility for specific antimicrobial usage and they also had major concerns about the
156 implications of any feedback on peer or supervisor judgement (Table 2). The challenges around
157 customised feedback centred on convincing NICU staff that national policies applied to their patients
158 (Table 2). Similar issues were encountered in a UK study of determinants of antimicrobial prescribing
159 in two hospitals, which showed that perceived threats to decision making autonomy and limitations
160 of local evidence-based policies were also encountered in interviews with a wide range of staff.³⁷
161 Etiquette (reluctance to be seen to criticise others) was a cross cutting theme that was embedded

162 within each of the other three themes (Table 3) and also probably contributed to the challenges
163 encountered in a NICU in the USA (Table 2).

164 Patel et al³⁶ believed that they had partially solved the challenge of timeliness by feeding back data
165 via two monthly meetings on the NICU supplemented with emails to staff before the meeting.

166 However, monthly, email feedback about time to first antibiotic dose had no effect in an
167 intervention designed to improve the management of sepsis on medical, general surgical and
168 orthopaedic continuing care wards in a UK hospital.³⁸ It was challenging to engage with senior
169 clinicians across multiple clinical units and teams.³⁸ The results of this study informed the design of
170 the measurement plan for a national Sepsis Collaborative in Scotland, in which clinical teams identify
171 patients with sepsis and use data collection sheets that include reminders about the actions to take
172 for patients with suspected sepsis, severe sepsis or septic shock.³⁹ This approach promotes
173 discussion about management of individual patients within clinical teams and so has the capacity to
174 address cultural challenges as well as enabling data collection.

175 In conclusion, the challenges to actionable feedback on antimicrobial prescribing to hospital
176 inpatients are most likely to be overcome by involving clinical teams in the collection of data in ways
177 that also remind them about actions they need to take to improve care. There is limited research
178 evidence about the issue of effective forms of safety feedback in healthcare compared with other
179 high risk industries. We need to draw on the valuable operational knowledge that exists within
180 diverse safety management communities. This shows that the design of effective feedback systems
181 depends on leadership, the credibility and content of information, effective dissemination channels,
182 the capacity for rapid action, and the need for feedback at all levels of the organisation.⁴⁰ Involving
183 clinical teams in data collection is feasible (Figure 3) and actionable feedback can be achieved
184 through review of individual cases.⁴¹

185 What explains variation in effectiveness of improvement interventions?

186 An example of a successful improvement intervention at scale is the Michigan ICU Project. This was
187 associated with significant reduction in central line associated blood stream infections in 103

188 participating ICUs from 7.7 per 1000 catheter days to 1.4 at 16 to 18 months of follow up.⁴² This
189 successful intervention was delivered through checklists, which reminded participants about the
190 care processes that needed to be implemented. In the UK the Matching Michigan study applied the
191 same checklist in 215 ICUs. Over the study period there was a steady reduction from 3.7 at baseline
192 to 1.5 central venous catheter blood stream infections per 100 catheter days but the reduction
193 began in the pre-intervention period. The implementation of the checklist was not associated with
194 any acceleration in the decline of infections. A possible explanation for these contrasting results is
195 provided by detailed ethnographic evaluations of both the original Michigan ICU study⁴³ and the UK
196 Matching Michigan study.⁴⁴ The results showed that the way the checklist was implemented in the
197 Michigan ICUs was best understood as a culture change intervention that made patient safety a
198 priority. The checklist was simply the mode of delivery, the mechanism of change was the way that
199 the checklist was used to promote discussion and teamworking.⁴⁵ Consequently there was no
200 guarantee that adopting the same checklists would achieve the same culture change in other ICUs.⁴³
201 In the UK the Matching Michigan intervention was actually associated with reduction in central line
202 blood stream infections in a minority of ICUs and the ethnographic research identified marked
203 differences between these ICUs *versus* the majority where the intervention had no effect.^{44, 46} The
204 interventions in the successful ICUs were characterised by embedding data collection into the daily
205 routine of the clinical teams with data sheets that reminded participants about important care
206 processes as well as by regular feedback and discussion of results. In contrast the interventions in
207 the unsuccessful ICUs were characterised by collection of information and decisions about infections
208 by people who were not members of the clinical teams responsible for delivery of the
209 intervention.^{44, 46}
210 The insights from the Michigan and Matching Michigan ICU studies^{43, 44, 46} can be used to explain
211 contrasting results of two studies that apparently used the same intervention to improve
212 antimicrobial prophylaxis for elective surgery. The Trial to Reduce Antibiotic Prophylaxis Errors
213 (TRAPE) randomised 22 participating hospitals in the USA to receive performance feedback alone

214 (Control) or to join an improvement collaborative in addition to receiving feedback (Intervention). The
215 results were similar to the Matching Michigan study⁴⁷ in that the outcomes improved significantly in
216 all participating hospitals but there was no evidence that the intervention had any additional
217 effect.⁴⁸ The authors concluded that *"the trial did not demonstrate a benefit of participation in a*
218 *quality improvement collaborative over performance feedback for improvement of these*
219 *measures."*⁴⁸ These results contrast with the success of an improvement collaborative to reduce
220 unnecessarily prolonged antimicrobial prophylaxis for coronary artery bypass graft (CABG) surgery in
221 Taiwan.⁴⁹ The design for this intervention was based on detailed analysis of a previous improvement
222 collaborative in orthopaedic surgery and included organising a team with senior leadership (hospital
223 superintendent), middle management (administration, financial), system leader (chairman of
224 Department) and clinical staff alongside a day to day project leader. The team reviewed the evidence
225 to support improvement targets and the workflow for administration of prophylaxis in CABG.
226 Measures for improvement were agreed and fed back to clinical teams. Whenever improvement in
227 outcomes occurred it was standardised by consolidation of work processes and the division of
228 cardiac surgery was complimented in public for the improvement.⁴⁹ In contrast The staff involved in
229 the improvement collaborative in TRAPE were "physicians and nurses involved in infection control"
230 and the authors note that "surgical staff or hospital leadership may have been insufficiently
231 involved."⁴⁸ The failure of the improvement collaborative in TRAPE is almost certainly due to the
232 fact that the investigators appeared to be unaware of key research about understanding the
233 variation in success of improvement collaboratives in other contexts, which shows that a key
234 difference between successful *versus* unsuccessful collaboratives is the ability to influence the
235 political cultural or leadership context.⁵⁰ In contrast with the US TRAPE study⁴⁸, the successful
236 Taiwan improvement collaborative explicitly recognised the need to address the political, cultural
237 and leadership context in the participating hospitals.⁴⁹
238 Implementing an intervention without asking why professionals currently do what they do and how
239 the intervention might help them to change is an example of what Mary Dixon Woods has called

240 “cargo cult quality improvement”.⁵¹ Cargo cult science was first described by the physicist Richard
241 Feynman. Cargo Cults occurred on remote islands in the South Seas at the end of the 2nd World War.
242 The reason was that aeroplanes had been delivering supplies throughout the war but then they
243 stopped coming. In order to make the aeroplanes come again the islanders made runways, built
244 aeroplanes, control towers and air traffic control equipment out of wood and waited for the
245 aeroplanes to land. They were baffled when nothing happened *The form is perfect. It looks exactly*
246 *the way it looked before. But it doesn’t work. No airplanes land. So I call these things Cargo Cult*
247 *Science, because they follow all the apparent precepts and forms of scientific investigation, but*
248 *they’re missing something essential, because the planes don’t land.”⁵²*

249 The aeroplanes delivered the supplies but the key question was why did they arrive? The answer
250 was the urgent but temporary need for the USA to get supplies to remote islands that were
251 previously of no strategic importance.

252 In summary, antimicrobial stewardship interventions have two major problems arising from failure
253 to apply evidence from the social sciences. The first problem is not including effective behaviour
254 change techniques in the design and reporting of interventions.¹⁷ The second problem is failure to
255 use theory to consider why and how an intervention like a checklist or an improvement collaborative
256 might work in a particular context.⁴⁶ The first problem is relatively easy to fix but the second
257 problem will require much more profound, interdisciplinary engagement with the social sciences.

258 Beyond Behaviour Change Techniques: Context, Systems Thinking and

259 Educational Research

260 The Importance of Context

261 Research on variation in the rate and pace of change in the health sector and other industries has
262 led to a key distinction between receptive *versus* non-receptive contexts.⁵³ A relevant example is the
263 analysis of variation in the effectiveness of the UK Orthopaedic improvement collaborative (Figure

264 4).⁵⁰ Although some variation was explained by the details of how the collaborative method was
265 adapted and how the improvement plan was implemented locally, context was the key explanatory
266 factor. Moreover the influence of context could be clearly separated into leadership, politics and
267 culture (Figure 4).

268 Listing the factors that lead to receptive contexts for change is a necessary starting point (Figure 4)
269 but it is *“the dynamic and ongoing interaction between these factors, rather than any one of them*
270 *individually or independently, that accounts for the effectiveness of QI intervention and the striking*
271 *variation between similar QI interventions in different places.”*⁵⁰ Moreover differences in context
272 within organisations can be greater than differences between organisations. A clear example is
273 provided by research with junior doctors in the first two years after qualification in two UK hospitals.
274 This showed extreme intra-hospital variation (Medicine was a completely different environment
275 from Surgery in Hospital A and in Hospital B with very little inter-hospital variation (Medicine in
276 Hospital A was similar to Medicine in Hospital B):⁵⁴

277 *“Our job really was to manage the more medical side of things and his job was the surgeon. ...*
278 *Umm, umm and it’s not it’s not like that at all in the medical side of the hospital it’s purely in*
279 *surgery and like the registrar who was almost a consultant some of them are fantastic but I think*
280 *probably half of them are, expect their FY staff to deal with things like prescribing antibiotics and*
281 *that kind of thing so they don’t really keep up-to-date with it erm and because they are so much*
282 *more of a surgeon than trying to treat things with medications they seem to be a bit out of*
283 *touch.”* Female F2, Location 1.⁵⁴

284 The components of context listed in Figure 4 are all examples of ‘inner’ context, which is the intra-
285 organisational leadership, politics and culture. It is equally important to consider the ‘outer’ context,
286 for example the health system and broader social, economic or political trends and events.⁵⁰ A
287 helpful account of inner and outer context is provided in a review of the literature about
288 implementation of new evidence in healthcare:⁵⁵

“Changes in the outer setting can influence implementation, often mediated through changes in the inner setting. Generally, the outer setting includes the economic, political, and social context within which an organization resides, and the inner setting includes features of structural, political, and cultural contexts through which the implementation process will proceed. However, the line between inner and outer setting is not always clear and the interface is dynamic and sometimes precarious. The specific factors considered ‘in’ or ‘out’ will depend on the context of the implementation effort. For example, outlying clinics may be part of the outer setting in one study, but part of the inner setting in another study. The inner setting may be composed of tightly or loosely coupled entities (eg, a loosely affiliated medical centre and outlying contracted clinics or tightly integrated service lines within a health system); tangible and intangible manifestation of structural characteristics, networks and communications, culture, climate, and readiness all interrelate and influence implementation.”

Antibiotic prescribing in hospitals involves multiple team members who are reluctant to change decisions made by others, particularly if they are more senior. To influence the antimicrobial prescribing of individual healthcare professionals, interventions need to understand prescribing etiquette and power relations by using clinical leadership within teams to influence practice.³⁷ Junior doctors make complicated antibiotic prescribing decisions in challenging contexts. Research in two UK hospitals identified two key problems: first conflicting advice given by senior staff and second a dearth of supervision or feedback.⁵⁴ The research team’s solutions to these problems included two interventions that applied the concepts of action planning and feedback. The first solution encouraged the explicit sharing of decision-making steps, so that junior doctors could see the rationales underpinning the prescribing decisions made by their seniors and discuss how they could apply these to their own decision making. The second solution was to provide junior doctors with a new model of support and feedback to provide them with the autonomy to work independently, whilst accessing support and receiving feedback regularly and when most needed.

315

316 In summary, context is a slippery subject because of the constant, dynamic interactions between
317 multiple components.⁵³ Achieving a good understanding of what a Quality Improvement (QI)
318 intervention is and how it works is always going to be less straightforward than understanding how
319 and why a drug works. In contrast, QI interventions with drugs are never likely to be completely
320 standardised or fully specified, indeed flexibility is essential for QI interventions to work at scale
321 across different contexts.⁵¹ We need to understand how social science studies running alongside QI
322 efforts can provide information that enhances the ability to adjust for context.⁵¹ However, I believe
323 that we can develop a better understanding how to improve complex systems through application of
324 established models derived from Human Factors and Ergonomics.

325 Improving Systems: Human Factors and Ergonomics

326 The International Ergonomics Association Council's official definition of ergonomics is:
327 "Ergonomics (or human factors) is the scientific discipline concerned with the understanding of
328 interactions among humans and other elements of a system, and the profession that applies theory,
329 principles, data and methods to design in order to optimize human well-being and overall system
330 performance."⁵⁶

331 Clinical Human Factors have been defined as: *"Enhancing clinical performance through an
332 understanding of the effects of teamwork, tasks, equipment, workspace, culture, organisation on
333 human behaviour and abilities, and application of that knowledge in clinical settings."*⁵⁶

334 Human Factors & Ergonomics are about designing systems that are resilient to unanticipated events
335 and addressing problems by modifying the design of the system to better aid people. Human Factors
336 & Ergonomics are not about eliminating human error or addressing problems by teaching people to
337 modify their behaviour.⁵⁷

338 Human factors work ranges from the individual to the organisational level.⁵⁷ Human factors &
339 Ergonomics are systems-orientated because people are just one embedded component of a complex

sociotechnical system and at the same time it is person centred. Human factors solutions use design of work structures and processes to improve patient, provider and organisational outcomes.¹⁸ Human Factors & Ergonomics and Quality Improvement Science developed from similar origins in the 20th century to engage workers in the identification of problems and development of solutions. They diverged from Quality Improvement Science by focussing more on reducing variation, increasing the reliability of production and listening to the voice of the customer, whereas Human Factors & Ergonomics focussed on staff wellbeing (occupational health and safety) and performance.⁵⁸ It is time to integrate these complementary approaches together in research and training to improve the safety of healthcare.⁵⁸

In the USA the Systems Engineering Initiative for Patient Safety (SEIPS) has developed a human factors model of person-centred sociotechnical systems (Figure 5). The first version of SEIPS was published in 2006⁵⁹ and the model has been refined by nearly ten years of application and research, including several relevant examples in medication safety and healthcare associated infection.¹⁸ In the SEIPS model, organisations, teams and technology are seen as interrelated components, the properties of which are changed if the system is dissembled in any way. The model emphasises that movement in one part of a healthcare organisation leads in a predictable fashion to movement in other parts. Moreover, healthcare organisations are open to environmental inputs, so that they are continually in a state of flux. The SEIPS model has four components: the work system, work processes, outcomes and adaptation. The work system is configured as dynamic and interactive. This affords insights into how actions or occurrences at one level (e.g., an error made by an individual) interact with phenomena at team (e.g., detection and mitigation of the error) and organisational (e.g., safety culture) levels of analysis. The SEIPS approach to work processes recognises that the individuals engaged in healthcare include patients and carers as well as healthcare professionals. Outcomes in SEIPS are separated into patient, professional or organisational, each of which is further divided into either desirable or undesirable and either immediate (proximal) or delayed (distal).

365 Finally the SEIPS model includes adaptation as a feedback mechanism that explains how dynamic
366 systems evolve in planned or unplanned ways.¹⁸

367 The SEIPS model provides a structure for investigation of the role of context in improvement. This is
368 necessary if we are to move beyond statements that “context is important” to explanatory models
369 that define what elements of context, under what circumstances, are important for human
370 performance.⁶⁰ A relevant example is developing a hypothesis about improvement through
371 identification of common factors between three organisations that have been the subject of public
372 enquiries into *Clostridium difficile* infection outbreaks. These were NHS Trusts in Northern Ireland,
373 Stoke Mandeville, and Maidstone and Tunbridge Wells.⁶⁰ Adopting a systems approach meant that
374 common contributory factors were identified at multiple levels in the external environment
375 (government, regulators), internal organisation (senior management, middle management), staff
376 (clinical practice) and the internal environment (equipment, buildings). The investigators found that
377 many individuals at ward level in all three Trusts were aware of the levels of poor hygiene and
378 inadequate patient monitoring practices, but saw no way to improve the situation. The investigators
379 concluded that many examples of staff behaviour within the three Trusts demonstrated
380 characteristics of ‘cultural entrapment’ of the type described in an analysis of the high rates of infant
381 mortality following heart surgery at Bristol Royal Infirmary. Cultural entrapment means that people
382 often fail to question their actions and overlook important cues that things are not as they think they
383 are. Consequently, system-wide organisational learning is inhibited and the inability to adapt and
384 learn from failure results in patterns of negative reinforcement which, in turn, act as a barrier to
385 change. The investigators hypothesis is that multi-level alignment and normalisation of risk related
386 behaviours in these three Trusts led to entrapment of staff into sub-optimal behaviour patterns.⁶⁰ A
387 successful intervention would need to change the culture in order to change behaviour by
388 encouraging reporting of incidents and providing actionable feedback.⁴⁰

389 The SEIPS model provides a structure to help practitioners to address the relationships between the
390 multiple, nested levels of the work system, care processes, outcomes and the unintended

391 consequences of change (Figure 5). Application to antimicrobial stewardship will be aided by
392 evidence from over eight years of research on using SEIPS to improve medication safety and reduce
393 healthcare associated infections.¹⁸ However, aligning medical education with these studies of
394 complex systems will be challenging.^{61, 62} Consequently the final section of this paper discusses
395 emerging approaches from educational research about learning about complexity in practice.

396 Learning in Practice

397 In the past fifteen years there has been significant innovation in the research of education and
398 lifelong learning with greater emphasis on how individuals and materials interact and how they are
399 related to the social context of complex systems.¹⁹ These ways of thinking about education and
400 learning are described as socio-material theories.⁶³ They focus on materials as dynamic and
401 enmeshed with human activity in everyday practices:

402 *“‘Material’ refers to the everyday stuff of our lives that is both organic and inorganic,*
403 *technological and natural, flesh and blood, forms and checklists, diagnostic machines and*
404 *databases, furniture and passcodes, snowstorms and dead cell zones and so forth. ‘Social’*
405 *refers to symbols and meanings, desires and fears and cultural discourses. Both material and*
406 *social forces are mutually implicated in bringing forth everyday activities.”⁶⁴*

407
408 In the natural sciences, complexity science is the study of the dynamics, conditions and
409 consequences of interactions.⁶⁵ Complexity theory describes a heterogeneous body of theories
410 originating in evolutionary biology, mathematics, general systems theories and specific applications
411 such as cybernetics.⁶³ In medical education there is growing awareness of the need to “embrace
412 diversity and complexity” in educational research and practice.⁶² Theoretical tools derived from
413 complexity theory could and should be used to help develop healthcare students’ capacity to take
414 appropriate action in the complex, multifaceted and interdisciplinary care situations that
415 characterise clinical practice.⁶¹⁻⁶⁵ In the broader field of professional education complexity theory is

416 just one of several socio-material approaches. Despite their different origins and purposes these
417 theories raise some common questions for educators aiming to support learning in practice (Table
418 4). These questions ask how learners interact with materials and how teachers enable them to
419 notice and adapt to cues in the environment. Moreover they encourage learners and teachers to
420 treat the environment as dynamic and to see a particular practice as nested within multiple complex
421 systems:

422 *“Students can learn to notice events that may be desirable or undesirable and, more*
423 *importantly to intervene by actively experimenting with the socio-material setting.”⁶³*

424 There are striking similarities between these socio-material approaches to learning and the systems
425 engineering approach to improving the complex work systems of patients and professionals (Figure
426 5). Consequently it is relevant to ask how do engineers learn about complex systems? The Royal
427 Academy of Engineering recently commissioned a report to address the UK shortage of engineers
428 through analysis of how schools, colleges and universities should teach engineering.⁶⁶ The report
429 identified six habits of mind which, taken together, describe the ways that engineers think and act
430 “to make ‘things’ that work or make ‘things’ work better” (Figure 6).⁶⁶ These are the same habits of
431 mind that are required to improve healthcare.⁶⁷

432 Can we teach medical students to think like engineers? At the University of Dundee we have been
433 enabling medical students to investigate incident reports in order to promote their understanding of
434 how errors occur and the systems in which they will be working.⁶⁸ We began with students in Final
435 Year but more recently have been working with students in second or third year on improvement
436 projects with support from the IHI (Institute for Healthcare Improvement) Open School³¹ and BMJ
437 Quality.³⁰ A recent, relevant example is a project to improve the recognition of post-operative acute
438 kidney injury after urological surgery.⁶⁹ The need for this work was identified in a study of the impact
439 on postoperative AKI (Acute Kidney Injury) of changing our hospital antibiotic policy for surgical
440 prophylaxis.⁷⁰ An unanticipated finding from this study was that postoperative SCr (Serum
441 Creatinine) was only measured in 52% of urology patients. This was concerning because the

442 prevalence of postoperative AKI was 16% in the patients with complete data. Two second year
443 students led an improvement project, which started with a task analysis of the processes for
444 measurement of preoperative and postoperative SCr (Figure 7). The process map for postoperative
445 SCr showed that the main problem was with patients discharged from the urology ward on the day
446 of surgery (Day 0) or on the day after (Figure 7a). Measurement of SCr was requested on these
447 patients but when phlebotomists came to the ward they were told the patient had been discharged.
448 The students found that most of these patients were in fact in the day room waiting for medicines
449 and for transport home. The process map for phlebotomy services (Figure 7b) established that it was
450 possible for blood samples to be taken from patients in the day room so the system was changed to
451 improve communication. This intervention increased reliability of postoperative SCr measurement in
452 urology⁶⁹ and has been taken over by NHS Tayside's Patient Safety team in order to ensure sustained
453 improvement. The students now understand that they will be working in complex systems where
454 apparently simple tasks may not be performed reliably. More importantly they have learned that
455 they can identify and test solutions that improve the system. This work has been made possible by
456 NHS Tayside's Patient Safety Network, which explicitly recognises the valuable work that students
457 can do to improve clinical care through projects that teach them about the health system.⁷¹ We are
458 currently involving about 30 students per year in improvement projects but the University of Dundee
459 has 160 medical students and 300 medical students in each intake year, with about 1700 students in
460 NHS Tayside in any calendar year. Through the Academic Health Sciences Partnership in Tayside⁷² we
461 aim to scale up to having at least 200 inter-professional improvement teams led by students and
462 Early Career Professionals (ECPs) within the next three years. ECPs are defined as those in their first
463 five years since qualification or in their first five years of management training. We are working with
464 Scottish Improvement Sciences Collaborating Centre on evaluation.⁷³ We hypothesise that forming
465 inter-professional improvement teams like this will enhance capacity and capability within and
466 across organisations.⁷³ We plan to evaluate this process by exploring:

- 467 • barriers and facilitators to successful completion of improvement projects by students and ECPs

468 • costs incurred by clinical teams and organisations from hosting QI projects
469 • the impact of QI projects on clinical team culture
470 • the ways in which QI projects facilitate organisational change
471 When people look out on their context, do they perceive an abundance of opportunity or a scarcity
472 of opportunity? Research shows that people at the top of an organisation are more likely to see an
473 abundance of opportunity whereas people at the bottom perceive their context as threatening or
474 limiting and are unwilling to participate in change.⁵⁰ We believe that supporting students and Early
475 Career Professionals to lead improvement projects will enable them to see an abundance of
476 opportunity and that this will also facilitate systems improvement at scale.

477 Conclusions and Actions for the Stewardship Community

478 There are three relatively simple actions that can be taken to enhance the science of improvement
479 for antimicrobial stewardship. Firstly, improve the design and reporting of interventions to change
480 practice through dissemination of evidence about effective behaviour techniques. Secondly, ensure
481 that interventions start by asking why people do what they do. Thirdly, think about why any
482 intervention might work and ask what works for whom and under what circumstances? However,
483 achieving sustained improvement at scale will only come through profound understanding of the
484 role of context. We need explanatory models that define what elements of context, under what
485 circumstances, are important for human performance. We also need to recognise the importance of
486 case studies for discovery and for developing and testing explanations for the consequences of
487 interventions.⁵¹ Case studies traditionally occupy the lowest rung in the hierarchy of medical science
488 but that view needs rethinking.⁷⁴ Medical journals should be aware of the innovative methodological
489 work that is taking place on case studies in the social sciences.⁵¹
490 Human Factors and Ergonomics and Improvement Science address context in different but
491 complementary ways. Human Factors and Ergonomics designs interventions based on understanding
492 human capabilities and limitations whereas improvement science focuses on how systems can

493 enable front line staff identify problems and test solutions.⁵⁸ Both approaches are socio-material and
494 would benefit from innovations in educational research and learning in other professional fields,
495 particularly design and engineering. Integration of these disciplines as complementary rather than
496 competing approaches to antimicrobial stewardship will require development of a shared agenda
497 through identification of themes that could be relevant across these different traditions of social
498 science. At the same time we need to rethink professional education in antimicrobial stewardship by
499 embracing complexity, learning in practice, learning in teams and changing culture by using students
500 and Early Career Professionals as Change Agents.

501 [Transparency declarations:](#)

502 I am the co-chair of the Quality and Safety Workstream of the Academic Health Sciences Health
503 Partnership in Tayside and lead for the Capacity and Capability Building Research Theme of the
504 Scottish Improvement Science Collaborating Centre, which are both cited in the references. No other
505 conflicts of interest.

506

507 References

- 508 1. Department of Health. UK 5 Year Antimicrobial Resistance Strategy 2013 to 2018.
509 [https://www.gov.uk/government/publications/uk-5-year-antimicrobial-resistance-strategy-2013-to-](https://www.gov.uk/government/publications/uk-5-year-antimicrobial-resistance-strategy-2013-to-2018)
510 [2018](https://www.gov.uk/government/publications/uk-5-year-antimicrobial-resistance-strategy-2013-to-2018) (17 December 2013).
- 511 2. Cronshaw HL, Daniels R, Bleetman A et al. Impact of the Surviving Sepsis Campaign on the
512 recognition and management of severe sepsis in the emergency department: are we failing? *Emerg*
513 *Med J* 2010; **28**: 670-5.
- 514 3. Daniels R, Nutbeam T, McNamara G et al. The sepsis six and the severe sepsis resuscitation
515 bundle: a prospective observational cohort study. *Emerg Med J* 2010; **28**: 507-12.
- 516 4. Kumar A, Roberts D, Wood KE et al. Duration of hypotension before initiation of effective
517 antimicrobial therapy is the critical determinant of survival in human septic shock. *Crit Care Med*
518 2006; **34**: 1589-96.
- 519 5. Davey P, Sneddon J, Nathwani D. Overview of strategies for overcoming the challenge of
520 antimicrobial resistance *Expert Reviews in Clinical Pharmacology* 2010; **3**: 667-86.
- 521 6. Kunin CM, Tupasi T, Craig WA. Use of Antibiotics A brief exposition of the problem and some
522 tentative solutions. *Ann Intern Med* 1973; **79**: 555-60.
- 523 7. Kunin CM. Problem of antibiotic usage. Definitions, causes, and proposed solutions. *Ann*
524 *Intern Med* 1978; **89**: 802-5.
- 525 8. Cooke D, Salter AJ, Phillips I. Antimicrobial misuse, antibiotic policies and information
526 resources. *J Antimicrob Chemother* 1980; **6**: 435-43.
- 527 9. Department of Health. UK Antimicrobial Resistance Strategy and Action Plan. 2000.
- 528 10. European Union Conference. The Copenhagen Recommendations. Report from the
529 Invitational EU Conference on The Microbial Threat. In: Rosdahl VK, Pedersen KB, eds. Copenhagen,
530 Denmark: Ministry of Health, Ministry of Food, Agriculture and Fisheries; <http://www.sum.dk/>, 1998;
531 1-52.
- 532 11. House of Lords Select Committee on Science and Technology. Resistance to Antibiotics and
533 Other Antimicrobial Agents. London, UK.: The Stationery Office, 1998; 1-108.
- 534 12. Shlaes DM, Gerding DN, John JF et al. Society for Healthcare Epidemiology of America and
535 Infectious Diseases Society of America Joint Committee on the Prevention of Antimicrobial
536 Resistance: guidelines for the prevention of antimicrobial resistance in hospitals. *Clin Infect Dis* 1997;
537 **25**: 584-99.
- 538 13. World Health Organization. WHO Global Strategy for Containment of Antimicrobial
539 Resistance. 2001.
- 540 14. Gawande A. Reith Lectures 2014: The Future of Medicine.
541 [http://www.bbc.co.uk/programmes/articles/6F2X8TpsxrJpnsq82hggHW/dr-atul-gawande-2014-](http://www.bbc.co.uk/programmes/articles/6F2X8TpsxrJpnsq82hggHW/dr-atul-gawande-2014-reith-lectures)
542 [reith-lectures](http://www.bbc.co.uk/programmes/articles/6F2X8TpsxrJpnsq82hggHW/dr-atul-gawande-2014-reith-lectures) (18 March 2015).
- 543 15. Davey P, Brown E, Charani E et al. Interventions to improve antibiotic prescribing practices
544 for hospital inpatients. *Cochrane database of systematic reviews (Online)* 2013; **4**: CD003543.
- 545 16. Davey P, Peden C, Brown E et al. interventions to improve antibiotic prescribing practices for
546 hospital inpatients (updated protocol). *Cochrane Database of Systematic Reviews* 2014; **8**.
547 <http://onlinelibrary.wiley.com/doi/10.1002/14651858.CD011236/abstract> (Access Date Access
548 2014, date last accessed).
- 549 17. Davey P, Peden C, Charani E et al. Time for action-Improving the design and reporting of
550 behaviour change interventions for antimicrobial stewardship in hospitals: Early findings from a
551 systematic review. *Int J Antimicrob Agents* 2015; **45**: 203-12.
- 552 18. Holden RJ, Carayon P, Gurses AP et al. SEIPS 2.0: a human factors framework for studying
553 and improving the work of healthcare professionals and patients. *Ergonomics* 2013; **56**: 1669-86.
- 554 19. Fenwick T, Edwards R, Sawchuk P. *Emerging approaches to educational research. Tracing the*
555 *sociomaterial*. Abingdon Oxon: Routledge, 2011.

20. Gardner B, Whittington C, McAteer J et al. Using theory to synthesise evidence from behaviour change interventions: The example of audit and feedback. *Soc Sci Med* 2010; **70**: 1618-25.
21. Ivers N, Jamtvedt G, Flottorp S et al. Audit and feedback: effects on professional practice and healthcare outcomes. *Cochrane database of systematic reviews (Online)* 2012; **6**: CD000259.
22. Lloyd RC. *Quality Health Care: A Guide to Developing and Using Indicators*. Sudbury, Massachusetts: Jones and Barrett, 2004.
23. The Health Foundation. Overcoming challenges to improving quality. 2012; 1-36.
24. Michie S, Richardson M, Johnston M et al. The Behavior Change Technique Taxonomy (v1) of 93 Hierarchically Clustered Techniques: Building an International Consensus for the Reporting of Behavior Change Interventions. *Ann Behav Med* 2013; **46**: 81-95.
25. Hoffmann TC, Glasziou PP, Boutron I et al. Better reporting of interventions: template for intervention description and replication (TIDieR) checklist and guide. *BMJ* 2014; **348**.
26. Michie S, Fixsen D, Grimshaw JM et al. Specifying and reporting complex behaviour change interventions: the need for a scientific method. *Implement Sci* 2009; **4**: 40.
27. Weinberg M, Fuentes JM, Ruiz AI et al. Reducing infections among women undergoing cesarean section in Colombia by means of continuous quality improvement methods. *Arch Intern Med* 2001; **161**: 2357-65.
28. Crombie IK, Davies HTO. Missing link in the audit cycle. *Quality in Health Care* 1993; **2**: 47-8.
29. Michie S, van Stralen MM, West R. The behaviour change wheel: a new method for characterising and designing behaviour change interventions. *Implement Sci* 2011; **6**: 42.
30. BMJ Group. BMJ Quality. <http://quality.bmj.com/> (14 November 2014).
31. Institute for Healthcare Improvement. IHI Open School Quality Improvement Practicum <http://www.ihl.org/offerings/IHIOpenSchool/Courses/Pages/Practicum.aspx> (30 July 2013).
32. Prior M, Elouafkaoui P, Elders A et al. Evaluating an audit and feedback intervention for reducing antibiotic prescribing behaviour in general dental practice (the RAPiD trial): a partial factorial cluster randomised trial protocol. *Implement Sci* 2014; **9**: 50.
33. SDCEP Scottish Dental Clinical Effectiveness Programme. Drug Prescribing for Dentistry. <http://www.sdcep.org.uk/?o=2334> (21 March 2015 2015, date last accessed).
34. Patel SJ, Oshodi A, Prasad P et al. Antibiotic use in neonatal intensive care units and adherence with Centers for Disease Control and Prevention 12 Step Campaign to Prevent Antimicrobial Resistance. *Pediatr Infect Dis J* 2009; **28**: 1047-51.
35. Patel S, Landers T, Larson E et al. Clinical vignettes provide an understanding of antibiotic prescribing practices in neonatal intensive care units. *Infect Control Hosp Epidemiol* 2011; **32**: 597-602.
36. Patel SJ, Saiman L, Duchon JM et al. Development of an antimicrobial stewardship intervention using a model of actionable feedback. *Interdisciplinary perspectives on infectious diseases* 2012; **2012**: 150367.
37. Charani E, Castro-Sanchez E, Sevdalis N et al. Understanding the determinants of antimicrobial prescribing within hospitals: the role of "prescribing etiquette". *Clin Infect Dis* 2013; **57**: 188-96.
38. Marwick C, Guthrie B, Pringle J et al. A multifaceted intervention to improve sepsis management in general hospital wards with evaluation using segmented regression of interrupted time series. *BMJ Qual Saf* 2013; doi:10.1136/bmjqs-2013-002176.
39. Scottish Antimicrobial Prescribing Group and Scottish Patient Safety Programme. Sepsis Collaborative Measurement Plan <http://www.knowledge.scot.nhs.uk/sepsisvte/sepsis.aspx> (23 March 2015).
40. Benn J, Koutantji M, Wallace L et al. Feedback from incident reporting: information and action to improve patient safety. *Qual Saf Health Care* 2009; **18**: 11-21.
41. Nelson EC, Splaine ME, Batalden PB et al. Building measurement and data collection into medical practice. *Ann Intern Med* 1998; **128**: 460-6.

607 42. Pronovost P, Needham D, Berenholtz S et al. An Intervention to Decrease Catheter-Related
608 Bloodstream Infections in the ICU. *N Engl J Med* 2006; **355**: 2725-32.

609 43. Dixon-Woods M, Bosk CL, Aveling EL et al. Explaining Michigan: developing an ex post theory
610 of a quality improvement program. *Milbank Q* 2011; **89**: 167-205.

611 44. Dixon-Woods M, Leslie M, Tarrant C et al. Explaining Matching Michigan: an ethnographic
612 study of a patient safety program. *Implement Sci* 2013; **8**: 70.

613 45. Dixon-Woods M, Leslie M, Bion J et al. What counts? An ethnographic study of infection data
614 reported to a patient safety program. *Milbank Q* 2012; **90**: 548-91.

615 46. The Health Foundation. Lining Up: How do improvement programmes work? , 2013.

616 47. Bion J, Richardson A, Hibbert P et al. 'Matching Michigan': a 2-year stepped interventional
617 programme to minimise central venous catheter-blood stream infections in intensive care units in
618 England. *BMJ Qual Saf* 2013; **22**: 110-23.

619 48. Kritchevsky SB, Braun BI, Bush AJ et al. The effect of a quality improvement collaborative to
620 improve antimicrobial prophylaxis in surgical patients: a randomized trial. *Ann Intern Med* 2008; **149**:
621 472-80, W89-93.

622 49. Sun TB, Chao SF, Chang BS et al. Quality improvements of antimicrobial prophylaxis in
623 coronary artery bypass grafting. *Journal of Surgical Research* 2011; **167**: 329-35.

624 50. Bate P. Context is everything. *Perspectives on context*. London: Health Foundation, 2014; 1-
625 30.

626 51. Dixon-Woods M. The problem of context in quality improvement. *Perspectives on context*.
627 London: Health Foundation, 2014; 87-101.

628 52. Feynman R. Cargo cult science: some remarks on science, pseudoscience and learning how
629 not to fool yourself. In: Robbins J, ed. *The Pleasure of Finding Things Out*. London: Penguin Books,
630 2007; 205-16.

631 53. Bate P, Robert G, Fulop N et al. Perspectives on Context. The Health Foundation, , 2014.

632 54. Mattick K, Kelly N, Rees C. A window into the lives of junior doctors: narrative interviews
633 exploring antimicrobial prescribing experiences. *J Antimicrob Chemother* 2014; **69**: 2274-83.

634 55. Damschroder LJ, Aron DC, Keith RE et al. Fostering implementation of health services
635 research findings into practice: a consolidated framework for advancing implementation science.
636 *Implement Sci* 2009; **4**: 50.

637 56. Clinical Human Factors Group. Towards a working definition of Human Factors in healthcare.
638 <http://www.chfg.org/news-blog/towards-a-working-definition-of-human-factors-in-healthcare> (8
639 February 2012).

640 57. Russ AL, Fairbanks RJ, Karsh BT et al. The science of human factors: separating fact from
641 fiction. *BMJ Qual Saf* 2013; **22**: 802-8.

642 58. Hignett S, Jones EL, Miller D et al. Human factors and ergonomics and quality improvement
643 science: integrating approaches for safety in healthcare. *BMJ Qual Saf* 2015; **24**: 250-4.

644 59. Carayon P, Schoofs Hundt A, Karsh BT et al. Work system design for patient safety: the SEIPS
645 model. *Qual Saf Health Care* 2006; **15 Suppl 1**: i50-8.

646 60. Karsh BT, Waterson P, Holden RJ. Crossing levels in systems ergonomics: a framework to
647 support 'mesoergonomic' inquiry. *Appl Ergon* 2014; **45**: 45-54.

648 61. Bleakley A. Blunting Occam's razor: aligning medical education with studies of complexity.
649 *Journal of evaluation in clinical practice* 2010; **16**: 849-55.

650 62. Martimianakis MA, Albert M. Confronting complexity: medical education, social theory and
651 the 'fate of our times'. *Med Educ* 2013; **47**: 3-5.

652 63. Fenwick T, Dahlgren MA. Towards socio-material approaches in simulation-based education:
653 lessons from complexity theory. *Med Educ* 2015; **49**: 359-67.

654 64. Fenwick T. Sociomateriality in medical practice and learning: attuning to what matters. *Med*
655 *Educ* 2014; **48**: 44-52.

656 65. Mennin S. Self-organisation, integration and curriculum in the complex world of medical
657 education. *Med Educ* 2010; **44**: 20-30.

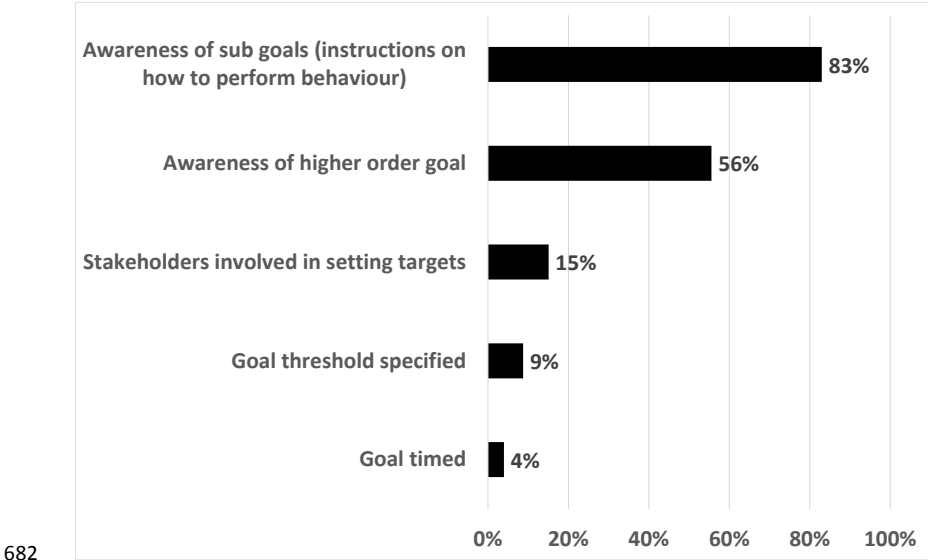
- 658 66. Lucas B, Hanson J, Claxton G. Thinking like an engineer. Implications for the
659 education system. London: Royal Academy of Engineering, 2014.
- 660 67. Lucas B, Nacer H. Habits of Improvers: thinking about education for improvement in health. .
661 London: Health Foundation, 2015 in press.
- 662 68. Davey P, Tully V, Grant A et al. Learning from errors: what is the return on investment from
663 training medical students in incident review? *Clinical Risk* 2013; **19**: 1-5.
- 664 69. Trotter N, Doherty C, Tully V et al. Improving the recognition of post-operative acute kidney
665 injury. *BMJ Quality Improvement Reports* 2014; **3**: doi:10.1136/bmjquality.u205219.w2164.
- 666 70. Bell S, Davey P, Nathwani D et al. Risk of Acute Kidney Injury with gentamicin as surgical
667 prophylaxis. . *JASN Journal of the American Society of Nephrologists* 2014; **25**: 2625-32.
- 668 71. NHS Tayside. NHS Tayside Patient Safety Network – Developing a Systematic Approach.
669 2014.
- 670 72. AHSP: Academic Health Sciences in Partnership in Tayside. AHSP Workstreams.
671 <http://www.ahspartnership.org.uk/ahsp/ahsp-workstreams> (17 May 2015).
- 672 73. SISCC The Scottish Improvement Science Collaborating Centre. Capability and Capacity
673 Building. <http://siscc.dundee.ac.uk/capability-and-capacity-building>.
- 674 74. Vandenbroucke JP. Observational research, randomised trials, and two views of medical
675 science. *PLoS Med* 2008; **5**: e67.

676

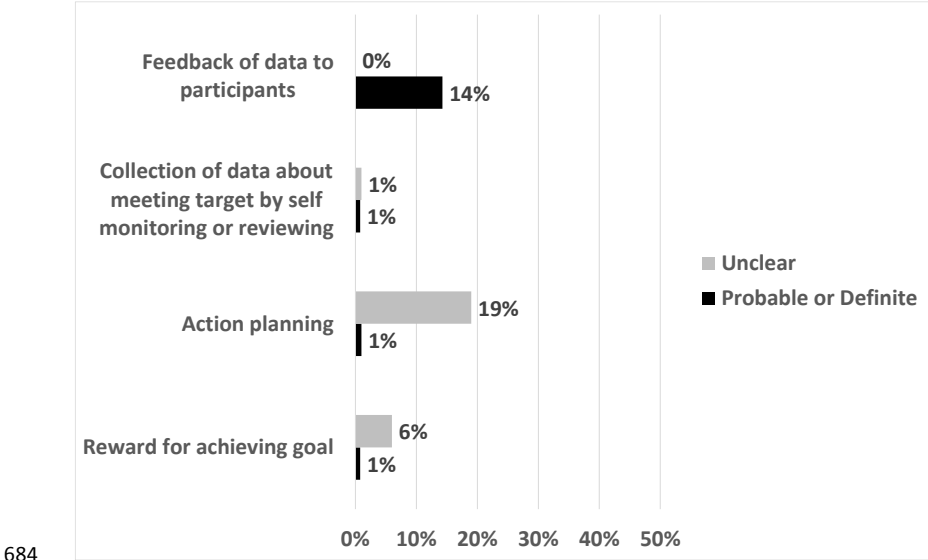
677

678

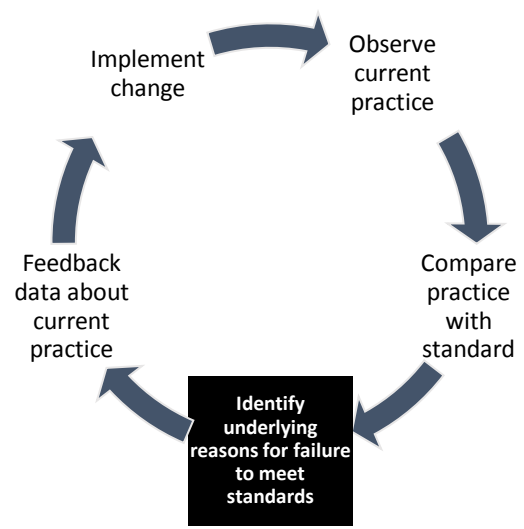
679 Figure 1: Goal setting, feedback and action planning for 123 interventions reported in 116 articles
680 about improving antibiotic prescribing to hospital inpatients. Drawn from data in Davey et al 2015.¹⁷
681 Figure 1a: Goal setting



682
683 Figure 1b: Feedback and action planning



685 Figure 2: The missing link in the audit cycle. Although many audit studies describe deficiencies in
686 health care, few identify the underlying causes. In consequence, the strategies for change which are
687 developed may not address the fundamental problems. An important link in the audit cycle is
688 missing, and failure to include this step is hampering the success of audit. Adapted from Crombie et
689 al 1993²⁸ with permission.

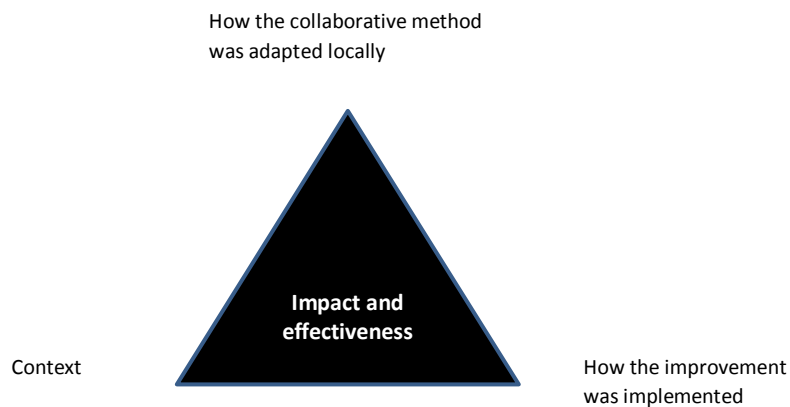


690
691

692 Figure 3: Eight Principles of Sustainable Measurement. From Nelson et al 1998⁴¹ with permission

- 693 1. Seek usefulness, not perfection in the measurement
- 694 2. Use a balanced set of process, outcome and cost measures
- 695 3. Keep measurement simple, think big but start small
- 696 4. Use qualitative and quantitative data
- 697 5. Write down the operational definitions of the measures
- 698 6. Measure small, representative samples
- 699 7. Build measurement into daily work
- 700 8. Develop a measurement team

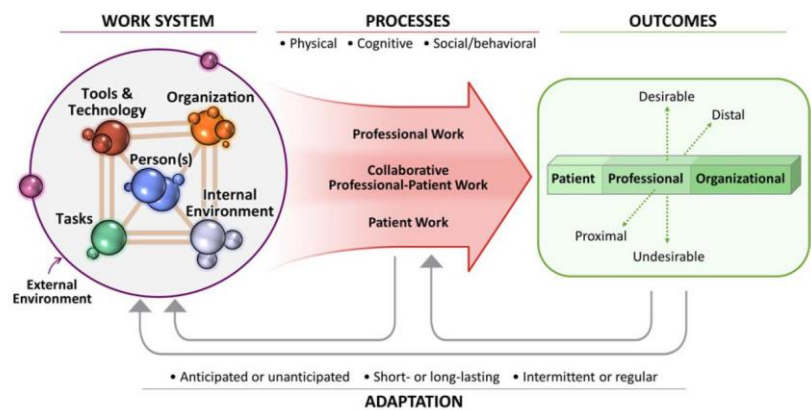
Figure 4: Factors explaining variation in the effectiveness of the UK Orthopaedic Services Collaborative in 2002. The primary outcome measure was length of stay and there was mean reduction by 13% for all hospitals in the collaborative. However, the range was from 3% increase to 43% decrease in length of stay. Three factors were identified to explain most of this variation but the most important of these was context. Adapted from Bate 2014.⁵⁰



Components of context:

1. Leadership
 - Style
 - Level of executive support
 - Local team leaders
2. Political
 - Empowerment
 - Mix of allies, adversaries and fence sitters
3. Cultural
 - Shared mind sets around quality and participation

710 Figure 5 The SEIPS (Systems Engineering Intervention in Patient Safety) Model, Version 2.0.
711 Reproduced with permission from Holden et al 2013.¹⁸



712

713

714 Figure 26 How to think like an engineer: six engineering habits of mind. From Lucas et al 2014⁶⁶ with
715 permission

- 716 1. Systems thinking: Seeing whole systems and parts and how they connect, pattern-sniffing,
717 recognising interdependencies, synthesising.
- 718 2. Problem-finding: Clarifying needs, checking existing solutions, investigating contexts, verifying.
- 719 3. Visualising: Being able to move from abstract to concrete, manipulating materials, mental
720 rehearsal of physical space and of practical design solutions.
- 721 4. Improving: Relentlessly trying to make things better by experimenting, designing, sketching,
722 guessing, conjecturing, thought-experimenting, prototyping.
- 723 5. Creative problem-solving: Applying techniques from different traditions, generating ideas and
724 solutions with others, generous but rigorous critiquing, seeing engineering as a 'team sport'.
- 725 6. Adapting: Testing, analysing, reflecting, rethinking, changing both in a physical sense and
726 mentally.

Figure 7: Process maps from a student led project to improve the identification of post-operative acute kidney injury for urology patients who received gentamicin prophylaxis. From Trotter et al 2014⁶⁹ (Slides 4 and 5 from Supplementary Material, Attachment 1- Baseline Data and Process Maps, available at <http://qir.bmj.com/content/3/1/u205219.w2164/suppl/DC1>) with permission.

Figure 7a: process map for measurement of post-operative creatinine by day of surgery

Key: DSU, Day Surgery Unit; Ward 9, Urology inpatient ward

Commented [PD1]: Figures replaced as requested by DR

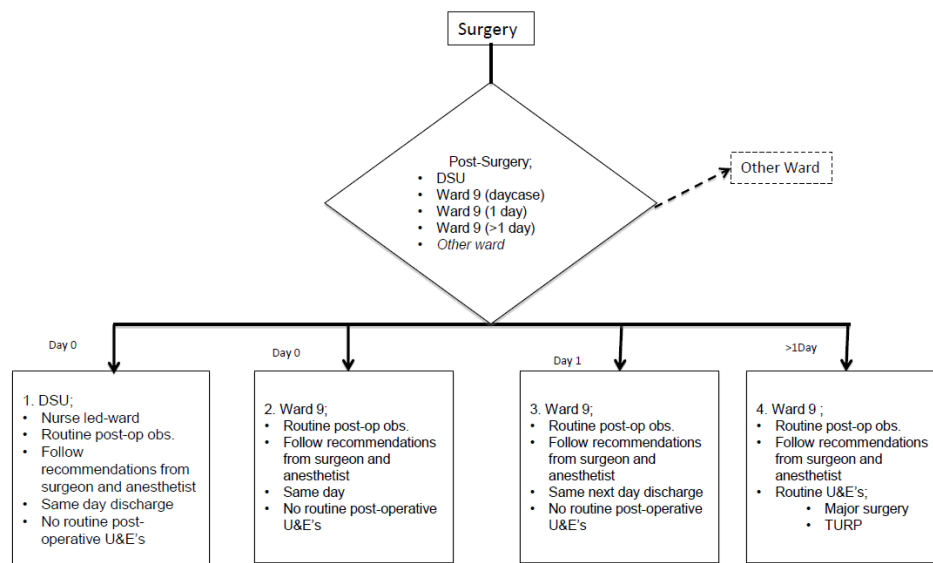


Figure 7b: process map for phlebotomy services on the urology ward

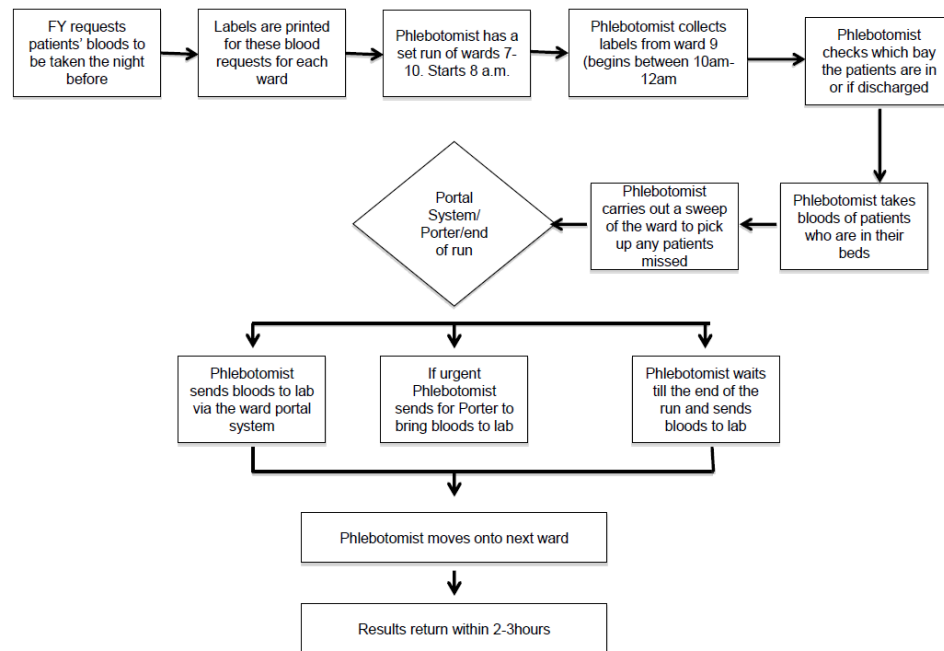


Table 1: Design of a Text Based Intervention designed to reduce use of antibiotics by dentists, modified from data in Prior et al 2014³² (Additional File 1, online only at <http://www.implementationscience.com/content/9/1/50/additional>). The intervention was added to feedback data about antibiotic use in the previous month.³² Guideline recommendations are from Scottish Dental Clinical Effectiveness Programme – Drug Prescribing for Dentistry: Dental Clinical Guidance, 2nd Edition.

Key: BCT Behaviour Change Techniques, the numbers refer to the classification in Michie et al:²⁴

BCT 36. Instruction on how to perform the behaviour (advise or agree on how to perform the behaviour)

BCT 78. Provide information about health consequences of performing the behaviour (note: consequences can be for any target, not just the recipient of the intervention)

Guideline Recommendation	BCT	Wording in the Text Based Intervention
Prescribing prolonged courses of antibiotic treatment can encourage the development of drug resistance	78	Merged to reduce text and edited (remove “prolonged” and change “drug” to antimicrobial:
Prescribing of antibiotics must be kept to a minimum	36	<i>“Prescribing courses of antibiotic treatment can encourage the development of antimicrobial resistance and therefore must be kept to a minimum”</i>
As a first step in the treatment of bacterial infections, use local measures. E.g. drain pus if present in dental abscesses by extraction of the tooth or through root canals, and attempt to drain any soft-tissue pus by incision.	36	Included without modification other than this additional text, based on evidence from dentist colleagues about potential influences on antibiotic prescribing: <i>“This should be the first step even if patients request antibiotics and even when time is short.”</i>
It is appropriate to prescribe antibiotics for oral infections where there is evidence of spreading infection (cellulitis, lymph node involvement, swelling) or systemic involvement (fever, malaise)	36.	Included but merged and shortened: <i>“Antibiotics are appropriate for oral infections where there is evidence of spreading infection, systemic involvement or persistent swelling despite local treatment”</i>
Other indications to prescribe antibiotics are acute necrotising ulcerative gingivitis and sinusitis, and pericoronitis where there is systemic involvement or persistent swelling despite local treatment	36	

Table 2: Challenges to actionable feedback for an intervention to improve appropriate antibiotic prescribing in a Neonatal Intensive Care Unit.³⁶

Process measure characteristic	Challenges	Key actions	Outcomes	Achieved
Timely	1. Data collection 2. Data presentation 3. Rare outcomes	1. Partial automation 2. Existing meetings 3. email	1. One month data delay 2. Two monthly meetings 3. Email pre meeting	Partially
Individualised	1. Rotating staff 2. Assigning responsibility for specific antimicrobial usage	Focus groups with prescribers to evaluate acceptance of individual feedback	1. Group feedback desired & provided 2. De-identified data	No
Nonpunitive	Concern about peer or supervisor judgement	1. Written informed consent from neonatologists 2. Certificate of confidentiality from National Institute for Nursing Research	98% eligible physicians enrolled and signed consent	Yes
Customised	Limitations of local evidence-based policies	1. Ethnography 2. Multi-centre antibiotic data ³⁴ 3. Clinical vignettes ³⁵	1. Prescriber involvement 2. Inter-disciplinary committee	Yes

Table 3: Determinants of antibiotic prescribing in hospitals, from data in Charani et al 2013³⁷ Etiquette is presented alongside the three main themes because it was found to be a cross cutting theme

1. Decision-making autonomy	<p><i>"Sometimes during a procedure, if the surgeon feels there's a need to introduce antibiotics, they say so and I have never challenged that, no one has ever challenged that."</i></p> <p><i>Nurse, Orthopedics (12 y)</i></p>	<p>4. Etiquette:</p> <p><i>"I think doctor to doctor, it's very difficult for clinician to clinician, especially different specialties to go and criticize one another. I think that's not collegial practice, so people don't want to do that."</i></p> <p><i>Nurse, Outpatient Parenteral Antimicrobial Therapy Services (14 y)</i></p>
2. Limitations of local evidence-based policies	<p><i>"Sometimes it is difficult to . . . use the policy because the policy will be your average sort of thing, it's not looking at someone at the top or at the bottom."</i></p> <p><i>Pharmacist, General Medicine (2 y)</i></p>	
3. Culture of hierarchy	<p><i>"The junior doctors tend to change it and the junior doctors won't change it if their senior doctors, if the consultant or registrar's specifically asked them to prescribe something else." . .</i></p> <p><i>Pharmacist, Intensive Care Unit (7 y)</i></p>	

Table 4: Common aspects of socio-material approaches to understanding education and questions these understandings raise for educators. Reproduced with permission from Fenwick and Dahlgren 2015.⁶³

Key socio-material understandings	Questions raised for educators
A focus on <i>materials</i> as dynamic and enmeshed with human activity Human meanings and decisions are important but are not the only things acting in any situation	How do particular materials and built environments affect what our students do and think? How might we encourage students to notice how materials influence situations in which they practise?
Emphasis is not on individual things and their characteristics, such as individual doctors' skills or particular technologies, but on their <i>relationships</i> and what these produce	How might students become more actively aware of these relations and their effects?
Practices themselves are continuously changing <i>gatherings</i> of human and non-human elements that act on one another in unpredictable ways	How do different elements act on one another to affect what happens, and how do these different interactions produce particular kinds of knowledge?
The <i>whole system</i> affects any particular practice as it continuously adapts and changes pattern	How is a particular practice interconnected with and affected by other systems?
<i>Uncertainty</i> and unpredictability are assumed	What might be inhibited in professional education dominated by predetermined curricula and planned objectives?